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THESIS

DEVELOPMENT OF SPREADSHEET
MODELS FOR FORECASTING MANPOWER
STOCKS AND FLOWS

by

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March 1998

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The computerized manpower planning models developed in this thesis were designed to be used by students taking the Manpower Personnel Models course, OS4701, in the Manpower Systems Analysis Curriculum at the Naval Postgraduate School. The purpose of the course is to introduce students to some of the basic manpower modeling concepts and these models are the prime instruments toward achieving that goal. The models constructed using Microsoft Excel™ include a Markov Chain Model, a One Grade Vacancy model, a Multigrade Vacancy model with Non-Instantaneous Filling of Vacancies, and a Vacancy model with Instantaneous Filling of Vacancies.

The models are designed to be run on personal computers with a Microsoft Windows 95™ operating system. User's manuals and example problems are included for each model in the appendices.

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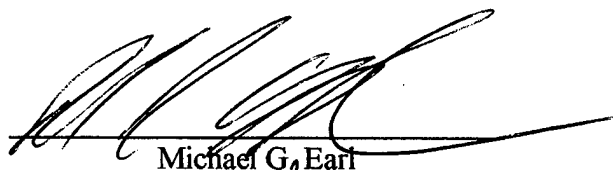Lieutenant, United States Navy
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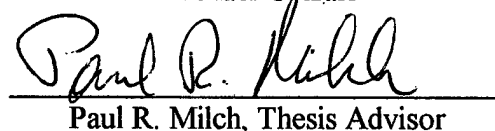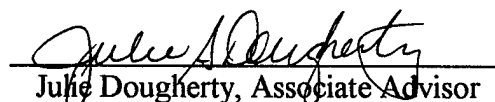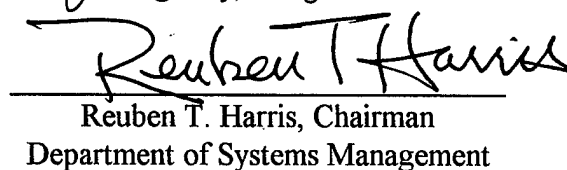
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ABSTRACT

The computerized manpower planning models developed in this thesis were designed to be used by students taking the Manpower Personnel Models course, OS4701, in the Manpower Systems Analysis Curriculum at the Naval Postgraduate School. The purpose of the course is to introduce students to some of the basic manpower modeling concepts and these models are the prime instruments toward achieving that goal. The models constructed using Microsoft Excel™ include a Markov Chain Model, a One Grade Vacancy model, a Multigrade Vacancy model with Non-Instantaneous Filling of Vacancies, and a Vacancy model with Instantaneous Filling of Vacancies.

The models are designed to be run on personal computers with a Microsoft Windows 95™ operating system. User's manuals and example problems are included for each model in the appendices.

THESIS DISCLAIMER

The reader/user is cautioned that the computer models developed in this research may not have been exercised for all possible cases. While every effort was made to ensure the models are free of computational and logic errors, they cannot be considered validated. Any application of these models, without additional verification, is at the risk of the user.

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ACKNOWLEDGMENT

I. INTRODUCTION

A. BACKGROUND

In general, manpower planning is a multi-disciplinary activity concerned with matching the supply of personnel with the jobs available (Ref. 1: p. V). Computer models are available to help personnel managers do their jobs more efficiently by accelerating the calculations used in predicting personnel flows with automation. As available market technology becomes more user-friendly, the expectations of users for that more user-friendly software increase.

The software produced in this thesis is designed for use in conjunction with the course OS4701, entitled "Manpower and Personnel Models". This is a required course in the Manpower Systems Analysis (MSA) curriculum at the Naval Postgraduate School. MSA graduates are required to "...have the ability to use and understand computer systems in problem solving..." (Ref. 2: p. 141). They also must be able to use advanced quantitative analysis such as "... Markov models in the analysis of force structure, manpower planning, forecasting and flow models." (Ref. 2: p.141). Keeping the course models up to date with regard to technology will allow the students to better meet the requirements of the curriculum.

The models that have been in use in the course were created by Ahmet E. Gurdal in 1991 and are thoroughly explained in Reference 3. These models are technically correct but lack a graphic interface. The technology used to create the models in the course has been overtaken by a more visual based interface, spreadsheets. The models produced for this thesis are built using a current computer software tool, a graphical interface driven spreadsheet. Today's users find any programs that do not have graphical interfaces to be a hindrance to learning. Spreadsheets are becoming one of the standard software tools used today by an increasing number of people in general, and by several curricula at the Naval Postgraduate School in particular. This spreadsheet technology, once learned, is transferable to other Microsoft Windows™ computer based systems. Many of the techniques can also be transferred to other software packages as well. Therefore, these models introduce the students to more resources for analyzing the data produced by these and other models.

The models produced in this thesis are more user-friendly than the models they are replacing. The improved user interface means the student does not need to spend as much

time learning how to use the model and can concentrate efforts on analysis of the results. With a spreadsheet as the underlying framework for these models, students can use the output from the models in further computations without cumbersome data input from the keyboard.

Since the primary goal of this thesis is to produce user-friendly models for students enrolled in the course, OS4701, every effort is made to reduce user confusion with regard to expected input values and steps needed to work the models. The models are Microsoft Windows™ based and therefore have graphical user interfaces. Each model is thoroughly documented and packaged in a format similar to all the models. The models are currently being tested in the course, OS4701.

The following models were developed to be used on a personal computer as part of this thesis:

1. The Basic Markov Chain model, MARKOV.XLS.
2. One Grade Vacancy model, REPLACE.XLS .
3. Multigrade Vacancy model with non-instantaneous filling of vacancies, VACANCY.XLS.
4. Vacancy model with instantaneous filling of vacancies, INSTANTANEOUS.XLS.

These models are explained in Chapters II, III, IV, and V, respectively. All models are programmed in Microsoft Excel™, the spreadsheet program currently accepted as the U.S. Navy's standard spreadsheet. The computer system and software requirements for the models can be found in Appendix A. Each model is provided with a user's manual in Appendices B, C, D and E, respectively. Each model is further explained through example problems presented in Appendices F, G, H and I.

B.   SCOPE OF THE THESIS

The primary intent of this thesis is to produce user-friendly Microsoft Excel™ models for use in the course, OS4701. User's manuals are also provided to help students make easy use of the models. These models are designed for the sole use of the course. Any use of these models in any other setting is not recommended.

The thesis will explain the basic equations, notations and procedures used in the creation of the models. It also explains some of the specific Microsoft Excel™ procedures and functions used in the creation of the models.

It is not the intent of this thesis to explain either manpower modeling theory or the general use of spreadsheet techniques. This thesis assumes the reader has a basic understanding of personal computer skills and is familiar with vectors and matrices.

1. Manpower Modeling Theory.

Manpower modeling theory may be learned for example, from Reference 1 or 4, or a combination of both. OS4701 is a course devoted to that goal at NPS.

2. Spreadsheets.

Spreadsheet modeling techniques should be learned in a specific course designed to teach spreadsheet techniques or by using a hands on approach and spreadsheet user's manuals. There are numerous spreadsheet user's manuals on the market. Users should find the manual that best suits their individual learning style, current level of competence and their learning goals.

C. AVAILABILITY OF MODELS

Copies of the models presented in this thesis are available from Professor Paul R. Milch in the Operations Research Department and Julie Dougherty in the Systems Management Department at the Naval Postgraduate School, Monterey, CA 93943. The models are also installed in the learning resource center computer lab located in Glasgow 203.

D. COPYRIGHT NOTICE

The models written in this thesis must be used with a registered copy of Microsoft Excel™. The models created by the author are placed in the public domain.

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II. THE BASIC MARKOV CHAIN MODEL

A.   INTRODUCTION TO THE MODEL

For personnel managers, the ability to accurately model their personnel system in such a way as to forecast the available workforce, accession needs, and losses due to attrition is vital. This ability allows personnel managers to test personnel policies on the model without the negative repercussions associated with the trial and error approach carried out on the real system of personnel. A Markov Chain model may be used for these purposes.

The first model developed for this thesis, MARKOV.XLS, forecasts stocks using internal flow rates, attrition rates, and recruitment flows. Based on an initial stock vector, a recruitment proportion vector, and a transition rate matrix, the model computes stocks by using Markov Chain Theory and a variety of planning scenarios.

A more detailed explanation of the theory and assumptions can be found in Reference 1, pages 95-115.

B.   BASIC EQUATIONS OF THE MARKOV CHAIN MODEL

The MARKOV.XLS model uses two forms of the Markov Chain equation, described in Reference 4, pages 6-22, to predict stock sizes under various "Recruitment Options". The two equations, and an explanation of the notation used, follow.

1.   Equation (1).

$$\underline{n}(t) = \underline{n}(t-1)\underline{P} + R(t)\underline{r}.$$

This equation is used to predict stock sizes in the various categories while controlling the number of personnel recruited during the forecasting period. The definitions of the notation used in the equation are:

a.   *$\underline{n}(t)$*.

$\underline{n}(t)$ is a vector of the category stocks at time t. This is the predicted stocks vector.

b.   *n(t-1).*

n(t-1) is a vector of the category stocks at the current time t-1. When t=1, this is n(0), the initial stock vector.

c.   *P and w.*

P is the transition rate matrix which governs the internal personnel flows. The P matrix and the attrition rate vector, w, are codependent. The relationship between them is: one minus the sum of the row elements in the P matrix equals the corresponding attrition rate element. For example, if the sum of the first row of a P matrix is .8, then the value of the first element of w is .2.

d.   *R(t).*

R(t) is the total number of personnel recruited, during the interval t-1 to t, who survive in the system until time t.

e.   *r.*

r is the recruitment proportion vector which determines how the R(t) recruits are distributed among the categories. Therefore, the sum of its components must equal one. For example, if r = (.85,.15,0), then 85 percent of the new recruits will enter category one, 15 percent of the new recruits will enter category two, and no recruits will enter category three.

2.   **Equation (2).**

$$n(t) = n(t-1)Q + M(t)r .$$

This equation is used to predict stock sizes in the various categories while controlling the size of the system during the forecasting period. . The definitions of the notation used in the equation are:

a.   *n(t), n(t-1), and r.*

n(t), n(t-1), and r are the same as previously explained.

b. _Q._

Q is a matrix similar to the matrix $\underline{P}$ used in equation (1). The $\underline{Q}$ matrix is derived by the following equation:

$$Q = \underline{P} + \underline{w}'\underline{r}$$

where $\underline{w}'$ is the column vector version of the row vector $\underline{w}$. For a more thorough explanation of this equation see Reference 4, pages 12-13.

c. _M(t)._

M(t) represents the change in system size during the interval , [t-1 to t). If N(t) is the system size at time t, and N(t-1) is the system size at time t-1, then:

$$M(t)=N(t)-N(t-1).$$

C. INPUT OPTIONS

To make user input easier, as well as foster a better understanding of the course material through visualization, three input options are provided for use with MARKOV.XLS. The three options which represent different scenarios in manpower planning are, length of service, hierarchical, and general.

1. Length of Service (LOS) System.

A system is called a LOS system if, during any one period, an individual in a category must either leave the system or move to the next higher category. An exception is made in the last category. Here during a period, an individual must either stay within that category or leave the system. Therefore, the $\underline{P}$ matrix of an LOS system has positive elements only in the cells immediately above the main diagonal and possibly in the last element of the main diagonal.

2. Hierarchical System.

A system is called hierarchical if, during any one period, the only personnel flows are promotion to the next higher category, attrition, or remaining in the original category.

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Therefore, there are no double promotions or demotions allowed in a hierarchical system. The $\underline{P}$ matrix of a hierarchical system can only have positive elements in the main diagonal and immediately above it.

3. General System.

The general system covers all possible situations. There are no restrictions on the placement of the positive elements in the transition matrix.

D. RECRUITMENT OPTIONS

Once the input option has been chosen, the model then allows the user to specify "Recruitment Options". The first three "Recruitment Options" are used to specify the manner in which accessions are brought into the system. The remaining three control system size and allow recruitment to conform accordingly.

1. Fixed Recruitment.

The number of personnel entering the system is fixed at the initial recruitment level, R.

2. Additive Increases or Decreases in Recruitment.

This option increases or decreases the initial recruitment by a set amount each period. For example, if the value -20 is entered in this option, then in each period the recruitment level is reduced by 20 until recruitment goes to zero.

3. Multiplicative Increases or Decreases in Recruitment.

This option increases or decreases the initial recruitment by a set percentage each period. For example, if the value .15 is entered in this option, then in each period the recruitment level is increased by 15 percent.

4. Additive Increases or Decreases in System Size.

This option increases or decreases the size of the system by a set amount each period. For example, if the value 200 is entered in this option, then in each period the system size is increased by 200.

5. Multiplicative Increases or Decreases in System Size.

This option increases or decreases the system size by a set percentage each period. For example, if the value -.05 is entered in this option, then in each period the system size is decreased by five percent until the system size goes to zero.

6. Fixed System Size.

This option holds the size of the system fixed at the level of the initial system size.

E. STEADY STATE

The equations used to derive the various steady state vectors that result from the six "Recruitment Options" are beyond the scope of this thesis. A detailed explanation of the steady state equations for each "Recruitment Option" can be found in Reference 5: pages 17-45.

1. Steady State Stock Vector, SSSV.

When computing successive stock vectors, it may be noticed under certain conditions, that the values of the components of $\underline{n}(t)$ remain the same beyond a certain value of t. Systems that reach this point are said to be in steady state. These values are called steady state stocks and their vector, $\underline{n}(t)$, is called the steady state stock vector. The SSSV exists in case of Recruitment Options:

a. Recruitment Options (1).

Fixed recruitment.

b. Recruitment Options (6).

Fixed system size.

2. Steady State Distribution Vector, SSDV.

When computing successive stock vectors, it may also be noticed under certain conditions, that the <u>distribution</u> of the components of $\underline{n}(t)$ remain the same beyond a certain value of t. In some scenarios it may not be possible for the stock sizes to reach steady state yet the stocks may reach steady state in their relative sizes to each other. In

this case, we say that "the system reaches steady state in distribution". The resulting vector of percentages is called the steady state distribution vector. A SSDV always exists when a SSSV exists. In summary, the SSDV exists under the following Recruitment Options and values.

    a.   Recruitment Option (1).

Fixed recruitment.

    b.   Recruitment Option (2).

Additive increase or decrease in recruitment with a <u>positive</u> additive increase.

    c.   Recruitment Option (3).

Multiplicative increase or decrease in recruitment with a <u>positive</u> multiplicative increase.

    d.   Recruitment Option (4).

Additive increase or decrease in system size with a <u>positive</u> additive increase.

    e.   Recruitment Option (5).

Multiplicative increase or decrease in system size with a <u>positive</u> multiplicative increase.

    f.   Recruitment Option (6).

Fixed system size

3.   The Zero Vector.

The zero vector is the value of both the SSSV and SSDV in case of the following Recruitment Options and values:

a. *Recruitment Option(2).*

Additive increase or decrease in recruitment with a <u>negative</u> additive increase.

b. *Recruitment Option(3).*

Multiplicative increase or decrease in recruitment with a <u>negative</u> multiplicative increase.

c. *Recruitment Option(4).*

Additive increase or decrease in system size with a <u>negative</u> additive increase.

d. *Recruitment Option(5).*

Multiplicative increase or decrease in system size with a <u>negative</u> multiplicative increase.

F.   USER'S MANUAL AND EXAMPLES

The user's manual for the MARKOV.XLS model is located in Appendix B. Appendix F contains three example problems using the MARKOV.XLS model.

III. ONE GRADE VACANCY MODEL

A. INTRODUCTION TO THE MODEL

The simplest of all vacancy models is the model with only one category. In a model of this type, there can be only two flows: attrition and recruitment. The model, REPLACE.XLS, computes replacement rates and numbers of recruits needed based on either attrition or survival behavior, length of service of personnel at time zero, and number of jobs created in each future period.

A more detailed explanation of the theory and assumptions can be found in Reference 1, pages 139-145, and Reference 4, pages 62-71.

B. ASSUMPTIONS AND NOTATION

Since there are no categories in a one grade vacancy model, the only flows that exist are either attrition out of the system, or recruitment into the system. For that reason, recruits are often referred to as replacements in this model. Attrition is thought of as occurring uniformly throughout the period and recruitment is thought of as occurring instantly at the end of the period.

1. Notation and Definitions.

The following notation and definitions are introduced:

a. f(i).

f(i) is the attrition rate among personnel with i years of service. f(i) may be interpreted as the probability that an employee, with at least i but less than i+1 periods of service, will leave the system before completing i + 1 periods of service. f(i) may also be interpreted as the proportion of employees, with at least i but less than i+1 periods of service, leaving the system before completing i + 1 periods of service.

b. G(i).

G(i) is the probability that an employee will survive in the system to i years of service or the proportion of such employees.

2. Relationship Between f(i) and G(i).

The relationships between the attrition rates, f, and the survivor rates, G, are the following:

a. *f(i)=G(i)-G(i+1).*

Given the G rates, the above formula computes the corresponding f rates.

b. *G(i+1)=G(i)-f(i).*

Given the f rates, the above formula computes the corresponding G rates using the additional fact that $G(0) = 1$.

C. SUBMODELS

Three specific submodels are discussed in this section. The differences among the three submodels hinge on the assumptions made in the definitions of each model. There is a natural progression of thought transcending the three submodels in which the first submodel makes three stringent assumptions and the remaining two submodels relax some of the assumptions in order to make the model more widely applicable.

1. Submodel A.

a. *Model Assumptions:*

(1) System size is fixed, at size N, at the end of each time interval.

(2) At time zero, all employees have zero years of service.

(3) All recruits entering the system start with zero years of service at their time of entry.

b. *Replacement Rates and Number of Recruits.*

The replacement rates, h(i), are computed using the formulas found in Reference 4: page 64. The number of recruits, R(i), is computed as:

$$R(i) = Nh(i)$$

where:

(1) h(i) = the rate at which recruits are hired during the period [i, i+1).

(2) R(i) = the expected number of replacements or recruits, during the period [i, i+1).

c.   *Steady State.*

The formulas for computing the steady state replacement rates and steady state number of recruits for submodel A are found in Reference 4: pages 67-69.

2.   Submodel B.

a.   *Assumptions.*

Submodel B makes the same assumptions as submodel A with the exception of assumption (2). In submodel B, assumption (2) is relaxed to allow a distribution of length of service among all personnel at time zero.

b.   *Replacement Rates and Number of Recruits.*

The replacement rates, h'(i), are computed using the formulas found in Reference 4: page 66. The number of recruits, R'(i), are computed as:

$$R'(i) = Nh'(i)$$

c.   *Steady State.*

The steady state replacement rates for Submodel B are the same as to those computed in submodel A.

3.   Submodel C.

a.   *Assumptions.*

Submodel C makes the same assumptions as submodel B with the exception of Assumption (1). Here, the original system size may be changed by the creation of M(i) new billets at future periods i = 1,2,....

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b. *Replacement Rates and Number of Recruits.*

The replacement rates, h''(i) and R''(i), are computed using the formulas found in Reference 4: pages 70-71.

c. *Steady State.*

The steady state number of recruits does not exist for submodel C. The steady state replacement rates are beyond the scope of this thesis.

D. USER'S MANUAL AND EXAMPLES

The user's manual for the REPLACE.XLS model is located in Appendix C. Appendix G contains three example problems using the REPLACE.XLS model.

IV. MULTIGRADE VACANCY MODEL WITH NON INSTANTANEOUS FILLING OF VACANCIES

A. INTRODUCTION TO THE MODEL

The purpose of a multigrade vacancy model is to forecast stocks of vacancies, numbers of personnel filling jobs, and flows of personnel. Unlike the single grade model, this model allows for the movement between categories within the system. VACANCY.XLS computes vacancies, available jobs, and the number of people, in each category, based on input criteria further described in this chapter.

A more detailed explanation of the theory and assumptions can be found in Reference 1, pages 152-156, and Reference 4, pages 71-81.

B. NOTATION AND DEFINITIONS

The following notation and definitions are used in the VACANCY.XLS model:

1. $\underline{n}(t)$.

$\underline{n}(t)$ is the vector of the number of jobs in each category at time t.

2. $\underline{v}(t)$.

$\underline{v}(t)$ is the vector of the number of vacancies in each category at time t.

3. $\underline{w}$ and $\underline{W}$.

$\underline{w}$ is the vector of personnel attrition rates in each category during any one period. $\underline{W}$ is a square matrix with the attrition rates in its main diagonal and zeros everywhere else.

4. $\underline{S}$.

The $\underline{S}$ matrix is the transition rate matrix which governs the internal vacancy flows among the categories.

5. $\underline{e}(t)$.

$\underline{e}(t)$ is the vector of the number of personnel in each category at time t. $\underline{e}(t)$ is computed using the formula:

$$\underline{e}(t) = \underline{n}(t) - \underline{v}(t).$$

6.   Alpha.

Alpha is the growth rate of jobs in each category during any period. Alpha can be positive, zero, or negative. A positive alpha would imply an increase in the number of jobs of all categories at that same rate. A zero value of alpha would indicate no growth in the number of jobs in all categories. A negative alpha would imply a decrease in the number of jobs of all categories at that same rate.

C.   BASIC EQUATION FOR COMPUTING VACANCIES

The basic equation used in predicting vacancies is:

$$\underline{v}(t) = \underline{v}(t-1)\underline{S} + \underline{e}(t-1)\underline{W} + \underline{n}(t)-\underline{n}(t-1).$$

The equation is explained through each of the three components.

1. $\underline{v}(t-1)\underline{S}$.

This term is the number, and location, of vacancies occurring due to the internal movement of vacancies over a period.

2. $\underline{e}(t-1)\underline{W}$.

This term is the number of vacancies created over a period due to personnel attritions from the system in all categories.

3. $(\underline{n}(t)-\underline{n}(t-1))$.

This term is the number of vacancies created, or eliminated, by the creation of new jobs, or the elimination of existing jobs.

D. ALGORITHM FOR COMPUTING VACANCIES

The model uses a ten step algorithm to compute vacancies successively at times t = 1, 2, ... The steps listed incorporate the restrictions imposed on the system by reality.

1. Compute $\underline{K}$.

$\underline{K}$ is the number of vacancies that are created in one period as a result of the internal movement of vacancies.

$$\underline{K} = \underline{v}(t-1)\underline{S}.$$

2. Compute $\underline{n}(t-1)$.

This is the vector of the numbers of jobs in each category at time t-1.

$$\underline{n}(t-1) = (1+\alpha)^{t-1}\,\underline{n}(0).$$

3. Compute $\underline{e}(t-1)$.

This is the vector of the numbers of personnel in each category at time t-1.

$$\underline{e}(t-1) = \underline{n}(t-1) - \underline{v}(t-1).$$

4. Compute $\underline{X}$.

Since a vacancy can move in one direction only when a person moves in the opposite direction, the number of vacancies created by internal vacancy movements cannot exceed the available number of people moving in the opposite direction.
$\underline{X}$ is the vector that ensures this rule is not broken.

$$\underline{X} = \text{Min}\,(\underline{K}\,,\underline{e}(t-1)).$$

5. Compute $\underline{Y}$.

$\underline{Y}$ is the vector of vacancies created by people leaving the system.

$$\underline{Y} = \underline{e}(t-1)\underline{W}.$$

6.   Compute $\underline{Z}$.

$\underline{Z}$ is the vector of vacancies created or eliminated by the creation or elimination of jobs during the period (t-1, t].

$$\underline{Z} = \alpha \underline{n}(t-1).$$

7.   Compute $\underline{U}$.

This step sums up the three ways vacancies may be created. To compute $\underline{U}$, add up the results of steps 4, 5, and 6.

$$\underline{U} = \underline{X} + \underline{Y} + \underline{Z}.$$

8.   Compute $\underline{Q}$.

$\underline{Q}$ is the vector that ensures that negative numbers of vacancies are not created in any category.

$$\underline{Q} = \text{Max}\,(\underline{U}, \underline{0}).$$

9.   Compute $\underline{n}(t)$.

This is the vector of the numbers of jobs in each category at time t.

$$\underline{n}(t) = (1+\alpha)\underline{n}(t-1).$$

10.   Compute $\underline{v}(t)$.

The number of vacancies cannot exceed the number of jobs in any category. This necessitates choosing the smaller value between components of $\underline{Q}$ and $\underline{n}(t)$.

$$\underline{v}(t) = \text{Min}\,(\underline{Q}, \underline{n}(t)).$$

E.   INPUT OPTIONS

To make user input easier, as well as foster a better understanding of the course material through visualization, two input options are provided for the VACANCY.XLS model. The two options are hierarchical and general.

1.   Hierarchical system.

A system is called hierarchical if, during any one period, the only flows are: vacancy demotions to the next lower category, vacancy attrition, or vacancies remaining unfilled in the same category. These correspond to personnel promotions, personnel attrition, and personnel transfer within the same category, respectively. There are neither double vacancy demotions nor promotions of vacancies allowed in a hierarchical system. For this reason, the $\underline{S}$ matrix of a hierarchical system can only have positive elements in the main diagonal and immediately below it.

2.   General system.

The general system covers all possible vacancy movement situations. There are no restrictions on the placement of the positive elements in the transition matrix.

E.   USER'S MANUAL AND EXAMPLES

The user's manual for the VACANCY.XLS model is located in Appendix D. Appendix H contains three example problems using the VACANCY.XLS model.

V. MULTIGRADE VACANCY MODEL WITH INSTANTANEOUS FILLING OF VACANCIES

A. INTRODUCTION OF THE MODEL

The purpose of the INSTANTANEOUS.XLS model is to forecast personnel movements during a period. This model operates under the assumption that all vacancies are filled instantaneously. While this concept may stretch reality, it may be a good approximation of systems that fill vacancies in time periods that are small fractions of their accounting periods. Since all vacancies are filled instantly, steady state is achieved during one period. Therefore, the only results of the model are steady state results. This model is not dependent on time.

A more detailed explanation of the theory and assumptions can be found in Reference 1, pages 146-152, and Reference 4, pages 81-86.

B. NOTATION, DEFINITIONS AND EQUATIONS

The following notation, definitions and equations are used in the INSTANTANEOUS.XLS model:

1. $\underline{n}$.

$\underline{n}$ is the vector of the initial number of jobs in each category.

2. $\underline{w}$.

$\underline{w}$ is the vector of personnel attrition rates in each category.

3. $\underline{m}$.

$\underline{m}$ is the vector of the number of jobs being created in each category during a period. A negative component of m implies that jobs are being eliminated in that category. For example, $\underline{m} = (5, -3, 0)$ implies that five jobs are created in category one, three jobs are eliminated in category two and the number of jobs in category three remains the same during the period.

3. $\underline{u}$.

This vector is given by the formula:

$$\underline{u} = (n_1 w_1 + m_1,\ n_2 w_2 + m_2,\ \ldots,\ n_k w_k + m_k).$$

Each component of this vector is the number of vacancies created in a category by the attrition of personnel and the creation/elimination of jobs in that category.

4. $\underline{q}$.

The vector is derived by taking the greater value in each category between the zero vector and $\underline{u}$. The formula is:

$$\underline{q} = \text{Max}(\underline{0},\ \underline{u}).$$

This formula assures that, in each category, the number of jobs eliminated does not exceed the number of jobs vacated by attriting personnel.

6. $\underline{S}$.

The $\underline{S}$ matrix is the transition rate matrix which governs the internal vacancy flows. The $\underline{S}_0$ matrix is the $\underline{S}$ matrix augmented with an additional column, the "0th" column, consisting of vacancy attrition rates. The transpose of $\underline{S}_0$, written as $\underline{S}_0'$, is the same matrix with the rows and columns interchanged. The $\underline{S}_0$ and $\underline{S}_0'$ matrices have the following appearances when constructed.

$$
\underline{S}_0 =
\begin{bmatrix}
s_{10} & s_{11} & s_{12} & \cdots & s_{1k} \\
s_{20} & s_{21} & s_{22} & \cdots & s_{2k} \\
s_{30} & s_{31} & s_{32} & \cdots & s_{3k} \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots \\
s_{k0} & s_{k1} & s_{k2} & \cdots & s_{kk}
\end{bmatrix}
$$

$$\underline{S_0}' = \begin{bmatrix} s_{10} & s_{20} & s_{30} & \cdots\cdots & s_{k0} \\ s_{11} & s_{21} & s_{31} & \cdots\cdots & s_{k1} \\ s_{12} & s_{22} & s_{32} & \cdots\cdots & s_{k2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ s_{1k} & s_{2k} & s_{3k} & \cdots\cdots & s_{kk} \end{bmatrix}$$

Note that the $\underline{S_0}'$ is a matrix with k+1 rows and k columns.

7. $\underline{D}$.

The $\underline{D}$ matrix is the inverse of the $\underline{I}$ - $\underline{S}$ matrix: where $\underline{I}$ is the identity matrix of the same size as $\underline{S}$. In equation form:

$$\underline{D} = (\underline{I}\text{-}\underline{S})^{-1}.$$

8. $\underline{f}$.

$\underline{f}$ is a vector produced by the matrix multiplication of $\underline{q}$ and $\underline{D}$. In equation form:

$$\underline{f} = (\underline{q})(\underline{D}).$$

This vector must be converted to a matrix with k+1 rows and k columns to conform to the size of $\underline{S_0}'$. Each of the k+1 rows are the same. This is accomplished by establishing the matrix $\underline{F}$ to have k+1 rows, each one identical to the vector $\underline{f}$. The matrix $\underline{F}$ has the form:

$$\underline{F} = \begin{bmatrix} f_1 & f_2 & f_3 & \cdots\cdots & f_k \\ f_1 & f_2 & f_3 & \cdots\cdots & f_k \\ f_1 & f_2 & f_3 & \cdots\cdots & f_k \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ f_1 & f_2 & f_3 & \cdots\cdots & f_k \end{bmatrix}$$

C. RESULTS

Because this model is not dependent on time, the results consist of a single matrix of personnel flows denoted by $\underline{P}$, a matrix of k+1 rows and k columns.

$$\underline{P} = \begin{bmatrix} P_{01} & P_{02} & P_{03} & \ldots\ldots & P_{0k} \\ P_{11} & P_{12} & P_{13} & \ldots\ldots & P_{1k} \\ P_{21} & P_{22} & P_{23} & \ldots\ldots & P_{2k} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ P_{k1} & P_{k2} & P_{k3} & \ldots\ldots & P_{kk} \end{bmatrix}$$

The element P_{ij} represents the number of personnel moving from category i to category j during a period. The $(P_{01}, P_{02}, \ldots, P_{0k})$ row represents the number of recruits entering each category of the system during a period.

This matrix is computed as an element by corresponding element multiplication of the $\underline{S}_0$' matrix and $\underline{F}$ matrix.

$$\underline{P} = \underline{S}_0' * \underline{F}$$

Notice that "*" refers to ordinary multiplication between two numbers, not the usual matrix multiplication. For example, P_{15} in the equation, $P_{15} = s_{51} * f_5$, refers to the number of personnel moving from category one to category five during a period.

E. USER'S MANUAL AND EXAMPLES

The user's manual for the INSTANTANEOUS.XLS model is located in Appendix E. Appendix I contains three example problems using the INSTANTANEOUS.XLS model.

VI. EXCEL MODELING FEATURES AND PROCEDURES

A.   FEATURES AND FUNCTIONS

It is not the intent of this thesis to explain all of the spreadsheet techniques used in the models created for this thesis. The features and functions described below are chosen because they are either used often in the models or they are rarely taken advantage of by the casual spreadsheet user.

1.   Macros.

Macros are Excel features that allow the user to perform a predetermined sequence of tasks with one click of a button. The advantage of macros is that the user can define the sequence of tasks to fit specifically to his own needs. Before creating a macro, it is advised that the user first test the desired process on an example of known result to make sure the correct result occurs. It is also suggested that the user write down the steps on a piece of scratch paper to be followed during the creation of the macro. Refer to either the help function or an Excel user's manual for more detailed information on how to create a macro.

2.   If, Then, Else.

The "If then" statement is a basic decision statement in computer programming. Excel is limited to an "If, then, else" statement. Since Excel is not a programming language, it is incapable of performing "If, then, do" functions. This limitation in Excel is the cause of the burdensome amount of "if" statements used in the formatting portions of the MARKOV.XLS model.

3.   Matrix Multiplication.

Matrix multiplication is the backbone of the mathematics used in the Markov Chain equations. Excel has a built in function designed specifically to handle matrix multiplication. The function does not permit invalid array entries which makes the function more user-friendly to the user who understands the rules of matrix multiplication. Before computing a matrix multiplication, the user must first highlight the destination vector or matrix. The highlighted area must be the proper size according to the rules of matrix multiplication. After entering the formula in the formula bar, Excel requires three

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keyboard keys to be pressed simultaneously. The three keys are, Control, Shift, and Enter.

4. Offset.

The "offset" function allows the user to select a value or an array of values, for display or further computation, based on a volatile input parameter. "Offset" can use a variable such as the forecast number of years and return the value of the result for the year forecast. This function is used often when follow on computations are required which are dependent on volatile input parameters.

5. Transpose.

The "transpose" function simply converts columns to rows and rows to columns. This function can be used on matrices as well as vectors. Although this does not sound like a function advanced enough to mention, its time saving quality is fantastic because, e.g. without this function, interchanging of rows and columns of a 20 X 20 matrix would require at least 400 individual cell entries.

6. Matrix inverse.

The matrix inverse function operates under similar rules as the matrix multiplication function described above. The matrix inverse returns the inverse of a square matrix. The user must be aware of the rules for taking the inverse of a matrix in order to highlight the appropriate destination area.

7. Maximum and minimum.

These two functions are used any time the user wants to know either the maximum or minimum value of an array. Alone these functions do little more than return a value. The power of these functions comes when embedding them in other functions or displaying ranges.

8. Count.

The "count" function simply counts the number of entries made in an array of cells. To make this function more useful, it is often used in conjunction with other

functions. Two specific cases are so common that software designers created special count functions for them:

a. Count blank.

"Count blank" counts all of the blank cells in an array. A cell with the value "0" entered in it is not counted as a blank cell. This is one of the few Excel functions that differentiates a zero from an empty cell.

b. Count if.

The "count if" function allows the user the ability to select the criteria by which the count function is constrained. The user can use a host of functions to create the criteria such as the maximum function explained above. It should be noted that this function can be recreated by the user by embedding a count function in an if statement.

9. Embedded/nested functions.

Excel allows the user to embed functions within functions many layers deep. The term "many" is used because there are limitations which vary from function to function, yet it is a rare case when this limit is reached in practice. The best way to visualize the process of embedding functions is to recall the complexities surrounding the use of parentheses in simple addition and multiplication. The user must keep track of the order of the functions to be performed. For many people, the steps used in formulating a series of embedded functions may get extremely confusing. For this reason, a sketch of a flow diagram is highly recommended for any user attempting to embed several functions. This flow diagram should be done before attempting to enter formulas into the formula bar.

B. MAKING CHANGES TO THE MODELS

All of the models created in this thesis are password protected. This is done so the user does not delete necessary cell information by accident. The models are both workbook and worksheet protected. If a worksheet is protected, it means that all protected cells in the worksheet cannot be changed by the user without unprotecting the worksheet first. If the workbook is protected, it means that all hidden sheets cannot be shown, the arrangement of displayed sheets cannot be altered and sheets cannot be added or deleted without unprotecting the workbook first. The only sheet not protected in any

of the models is the "Student Worksheet". Only an experienced user should attempt to make alterations to a model.

To make changes to any of the models in this thesis, the password that protects the workbook and worksheets from tampering must be known. The password used in all workbook and worksheet protections is the same. To unprotect either a workbook or worksheet, click on the "Tools" drop down menu located at the top of the screen, select "Protection", and choose either the sheet or the workbook, depending on the type of changes being made. Then enter the password exactly as given below. The password used in all of the models is CURTIS. It is important to remember that the password is case sensitive. This password is an all capital letter, six letter word, with no punctuation or spacing.

APPENDIX A. COMPUTER SYSTEM HARDWARE AND SOFTWARE REQUIREMENTS

There are certain minimum levels of computing power and technology required to operate the models discussed in this thesis. These requirements are separated into two categories. The two categories are system hardware requirements and model software requirements.

A. SYSTEM HARDWARE REQUIREMENTS

MARKOV.XLS, REPLACE.XLS, VACANCY.XLS and INSTANTANEOUS. XLS are designed for use on personal computers. There must be at least five megabytes (MB) of memory remaining on the hard drive in order to load all three models. The computer must run at a speed of at least 100 MHz. The computer must have a minimum of eight MB of random access memory. The system must be equipped with a mouse.

At this time, current technology is much greater than the minimum system requirements described above. The models run faster on higher capacity personal computers. For this reason, it is recommended that the user exceed the minimum system requirements.

B. SOFTWARE REQUIREMENTS

The computer must be operating on the Microsoft Windows 95™, or higher, operating system. The computer must have Microsoft Excel™ version 7.0 for Windows 95™, or higher. At this time there is a version of Excel™ more advanced than Excel™ 7.0 for Windows 95™. There is no increased performance gained by using newer software packages to run the models. If a newer version of Excel is the most commonly used version, it might be easier to run the model in the newer version. As mentioned above, this will not enhance performance; it will make loading the model more convenient.

APPENDIX B. USER'S MANUAL FOR THE BASIC MARKOV CHAIN MODEL

A. LOADING THE MODEL

In order to use this Excel based model, the user must first open the Excel program that meets the compatibility requirements stated in Appendix A. Once Excel is open, the user should open the file "MARKOV.XLS" located in the subdirectory of the drive in which the model is contained. For users in the Learning Resource Center lab, Glasgow 203, this subdirectory and its location will be provided by the instructor. Users who load the application on their home computer will find the file in the subdirectory to which the user had copied it earlier.

B. RUNNING THE MODEL

1. Step (1) Start.

Once the model is displayed on the screen, select the "Start" sheet by clicking on the tab at the bottom of the spreadsheet. A simplified step by step guide to the MARKOV model is presented on this sheet. A cell for the user's name is also provided here. For the inexperienced user, it is recommended that the "Start" sheet be printed and the instructions on it be followed.

2. Step (2) Choose Model Option.

Next, the user should select the appropriate tab at the bottom of the spreadsheet, corresponding to the Markov model that best represents the problem. The three options are: Length of Service (LOS), Hierarchical (Hier), and General (Gen). For an explanation of the constraints and guidelines for these three options, refer to Chapter II of this thesis.

3. Step (3) Data Input.

a. *Initial Stock and Recruitment Proportion Vectors.*

All three of the above options require the input of an initial stock vector and a recruitment proportion vector. The user is limited to no more than 20 categories and the recruitment proportion vector must sum to one.

b. Transition Matrix.

Each option requires specific input to derive the transition rate matrix. The following explanations detail the specific input requirements for each option:

(1) LOS option. The user must input <u>either</u> the attrition rates <u>or</u> the continuation rates in order for the spreadsheet to develop the entire transition rate matrix.

(2) Hierarchical option. The user must input <u>both</u> the attrition rates <u>and</u> the promotion rates in order for the spreadsheet to develop the entire transition rate matrix.

(3) General option. The user must input all <u>positive</u> elements in the transition rate matrix.

c. Recruitment Options.

Once the transition rate matrix is established, the user must choose one of the six "Recruitment Options". If the user does not make an entry in the Recruitment Option section, then "Recruitment Option 1" is automatically selected by default. In order to make an entry in the Recruitment Option cells, the user must input the appropriate value in the cell corresponding to the option selected. An explanation of each of the six possible options follows:

(1) Fixed recruitment. This is the default setting and requires no entry in the Recruitment Option section. However, this option requires an input in the cell for initial recruitment.

(2) Additive increase or decrease in recruitment. This option requires an entry in two cells. The first entry is a value in the Recruitment Option block equal to the amount by which the user wants total recruitment to increase/decrease each year. The second entry is the initial recruitment. For example, if the user wants to start with an initial recruitment of 1000 and wants to decrease recruitment by 50 each year, then the user must enter "-50" in "Recruitment Option 2" and "1000" in the initial recruitment cell.

(3) Multiplicative increase or decrease in recruitment. This option also requires entries in two cells. The first entry is a value in the Recruitment Option block equal to the percentage the user wants total recruitment to increase/decrease each year. The valid values that can be entered in the Recruitment Option cell range from -1 to

1, not including zero. The second entry is the initial recruitment. For example, if the user wants to start with an initial recruitment of 1000 and wants to increase recruitment by 5 percent each year, then the user must enter ".05" in "Recruitment Option 3" and "1000" in the initial recruitment cell.

(4) Additive increase or decrease in total system size. This option requires a value in "Recruitment Option 4" equal to the number by which the user wants the total system size to change each year. There is no input of initial recruitment here as that is not a value to be chosen by the user. For example, if the user wants to increase the total system size by 100 per year, then the user must enter "100" in "Recruitment Option 4".

(5) Multiplicative increase or decrease in total system size. This option requires a number in the range of -1 to 1, not including zero, to be put into "Recruitment Option 5". This number represents the percentage change to the total system size each year. There is no input of initial recruitment here as that is not a value to be chosen by the user. For example, if the user wants to decrease the total system size by three percent each year, then the user must enter "-.03" in "Recruitment Option 5".

(6) Fixed total system size. This option requires the number "1" to be entered in "Recruitment Option 6". This holds the system size to the sum of the initial stocks for the base year. There is no input of initial recruitment here as that is not a value to be chosen by the user.

d. *Initial Recruitment.*

Initial recruitment is only needed for Recruitment Options (1), (2), and (3). As explained above, there is no input of initial recruitment in Recruitment Options (4), (5), and (6) as it is not a value to be chosen by the user.

e. *Base Year.*

The base year, e.g. 1998, can be entered by the user or left blank. If left blank, the default base year is "0". The term "year" may also mean some period of other than one year in duration, such as a month or a quarter.

f.   *Initial Forecast.*

This cell requires the number of years the user wants to forecast under the Recruitment Option previously selected. This number must be a positive integer no greater than 35. In order to forecast a larger number of periods, use the "Reinitialize" feature explained below without altering the Recruitment Options or any other parameters.

4.   Step (4) Reinitializing.

The Reinitialize procedure is used when the user wants to forecast starting with the results obtained from the previous forecast. The user can alter the Recruitment Option and the transition rate matrix. However, the user can not move between one of the Markov model options to a different option. For example, the user can not switch from the LOS option to the General option or vice versa.

a.   *Prior to Reinitializing.*

The user may want to copy the results from the initial forecast to the worksheet. This procedure is outlined in section 6 of this appendix. It is also advised that the user print out the input page as these numbers will change after reinitializing. To see how to print, go to section 7 of this appendix.

b.   *Keeping Track of Periods.*

The easiest method for keeping track of the years is to recognize that the application is always in the base year displayed on the input sheet and is set to forecast into the future.

c.   *Pressing the "Reinitialize" Button.*

If the user wants to do <u>additional</u> forecasting, he must click the macro button labeled "Reinitialize" located directly to the right of the forecast input cell. The model then moves the base year ahead by the number of years in the previous forecast, and reinitializes the initial stock and recruitment values.

d. *Making Changes.*

The user can now alter the Recruitment option, and change other parameter values within the confines of the problem, to forecast over the next period of years.

e. *Entering Forecast Value.*

When all changes are made, the user should enter in the forecast cell, the number of additional periods to forecast.

5.   **Step (5) Display Results.**

The results of the application are displayed on three different sheets labeled: "Forecast", "% Initial CS", and "% Current SS". The description of the contents of each sheet follows:

a. *Forecast.*

This sheet displays the steady state stock vector (SSSV) and the steady state distribution vector (SSDV) when they exist. Displaying the total recruitment, the total system size, and the stock values for each category for each forecasting year are the main features shown on this sheet.

b. *% Initial CS.*

The percent of the initial category size sheet displays the steady state stock vector (SSSV) and the steady state distribution vector (SSDV) when they exist. Here the SSDV is a vector of steady state stock sizes expressed as percentages of the initial category sizes. Likewise, the sheet displays, for each forecasting year, the stock values in each category as percentages of the initial category sizes. These values can be used to compare individual category sizes to the original category size.

c. *% Current SS.*

The percent of current system size sheet displays the steady state stock vector (SSSV) and the steady state distribution vector (SSDV) when they exist. In addition, the sheet displays the stock values in each category over time as a percentage of

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the total system size each year. These values can be used to compare the changes between categories over time.

6. **Step (6) Combine Results of the Initial Forecast and Additional Forecasts.**

The user may want to copy the results of each forecast to the "worksheet" in order to maintain a chronological listing of results. Failure to do so will erase previous inputs and results. The results can be used for graphing trends or simply consolidating the information to one sheet.

a. *To Copy to the Worksheet, the User Must Follow these Steps:*

- Select/highlight the entire area needed to be copied with the mouse.

- Do not include the initial values in the copying as they are equal to the values in the last year of the initial forecast. For example, if the user did an initial forecast of five years, the initial values of the additional forecast are equal to the results of the initial forecast in year five.

- Copy, by choosing either of the two steps below.

  - Click the "copy" icon in the toolbar.

  - Using the Edit drop down menu, choose "copy".

- Select the "Worksheet" tab at the bottom of the screen.

- Select the cell where the upper left-hand corner of the data is to be placed by moving the cursor to that cell.

- Choose the "Paste Special" macro at the top of the sheet.

b. *If the User Needs to Graph the Results:*

Copy the values to the "Worksheet" and create all graphs on the "Worksheet". All other sheets are protected and do not permit graphing.

7. Step (7) Printing.

There are several ways to use the "Windows" print functions. One option is to set the print area to encompass only the portion needed. The other option is to print only the first page on any sheet. To set the print area, the user must highlight the cells to be printed with the mouse. Then using the function located on the File drop down menu, set the print area. Once set, just press the print icon on the toolbar. To print only one page, the user must select the print command on the File drop down menu and change the commands in the dialog box to "pages 1 to 1" instead of "All". Failure to do so results in the printing of blank pages.

a. Input.

The user can choose either printing option if the system contains no more than nine categories when printing the input sheet. Using other methods to print may result in printing blank pages in addition to the desired result. If there are more than nine categories, just hit the print icon and the result is two printed pages.

b. Results.

For all of the result pages it is recommended that the user prints page "1 of 1" for all systems with ten categories or less, otherwise blank pages will be printed. If there are more than ten categories, hitting the print icon is sufficient.

c. Worksheet.

Since this is an unprotected sheet, it is the user's responsibility to print only the data needed. The "set print area" method is recommended for this printing.

C. ERROR TRAPPING/WARNING

1. Error Displays.

Errors are displayed in bold red letters on the screen. Error messages will only appear when there is an error and they will disappear when the error is corrected. Some mistakes cause two errors to appear. The user should double check the input sheet for any red error messages before looking at the results.

## 2.	Consequences of Ignoring Warnings.

If the user ignores the warnings, this application may allow the invalid numbers to be used. It will use the flawed inputs and return flawed forecasts. Some warnings come with suggested fixes for the more common errors.

APPENDIX C. USER'S MANUAL FOR THE ONE GRADE VACANCY MODEL

A.   LOADING THE MODEL

In order to use this Excel based model, the user must first open the Excel program that meets the compatibility requirements stated in Appendix A. Once Excel is open, the user should open the file "REPLACE.XLS" located in the subdirectory of the drive in which the model is contained. For users in the Learning Resource Center lab, Glasgow 203, this subdirectory and its location will be provided by the instructor. Users who load the application on their home computer will find the file in the subdirectory to which the user had copied it earlier.

B.   RUNNING THE MODEL

1.   Explanation of the Three Submodels.

There are three submodels used in the one grade vacancy model. Below is a description of each of the three submodels and the assumptions differentiating between them.

A.   *Submodel A.*

Submodel A makes the following three assumptions:

(1) System size is fixed, at size N, at the end of each time interval.

(2) At time zero, all employees have zero years of service.

(3) All recruits entering the system start with zero years of service at their time of entry.

B.   *Submodel B.*

Submodel B makes the same assumptions as submodel A with the exception of assumption (2). In submodel B, assumption (2) is relaxed to allow a distribution of length of service among all employees at time zero.

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C.   Submodel C.

Submodel C makes the same assumptions as submodel B with the exception of Assumption (1). Here, the original system size may be changed by the creation of new billets from time to time.

2.   Data Input.

Once the model is displayed on the screen, select the "Input" sheet by clicking on the tab at the bottom of the spreadsheet. A cell for the user's name is also provided on this page. The user can only enter data in the green cells. For data with more than 15 entries, use the second layer of input cells in the same manner as in the first layer. The input parameters are further described below.

a.   User's Name.

The purpose of this entry is to identify the user on both the input sheet as well as the results sheet.

b.   N.

N denotes the initial system size. If N is not given directly, the user may be able to derive it from other information in the problem, such as the initial LOS distribution of employees.

c.   Attrition Rates, f, or Survivor Rates, G.

The user can enter either the f rates or the G rates. The rate, f(i), is the probability that an employee leaves the system with LOS in the range [i, i+1). The rate G(i) is the probability that an employee has LOS i or greater. The user cannot enter both rates. The user can enter no more than 32 f rates or 31 G rates. By definition, G(0) is equal to one, and is therefore automatically entered.

If the user enters less than 32 f rates, and the sum of the f rates is less than one, the model apportions the difference between one and the sum of the entered f rates equally among the remaining f rates. These computed values, together with the entered values, are displayed at the bottom of the input page. A reminder is provided informing the user which f rates are calculated by the computer, based on the f rates entered by the user.

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If the user enters less than 31 G rates, and the last G rate entered is not equal to zero, the model assumes that the last G rate must be reduced gradually by equal amounts in each cell until the last G value is equal to zero. All of these values are displayed at the bottom of the input page. A reminder is provided informing the user which G rates are calculated by the computer, based on the G rates entered by the user.

d. S.

S(i) denotes the number or proportion of initial employees with LOS between i and i+1 for i values 0,1,2,...31. These S(i) numbers can be entered as either the actual numbers of employees or as their proportions. For example, the entries: 1000, 500, and 500 would indicate that at time zero 50 percent of the employees have zero years of service, 25 percent of the employees have one year of service, and 25 percent of the employees have 2 years of service. No other entry in the S field indicates that there are no initial employees with more than 2 years of service. No entry in any of the cells of this section produces results under the assumptions of submodel A or submodel C, depending on the entries in the M field described next.

e. M.

M(i) denotes the number of billets created at time i. These inputs must be either zero or positive integers. Since the initial system already encompasses billets in period zero, new billets can be created only in period one or later. If no entry is made in any cell of this section the results produced are under the assumptions of submodel A or submodel B, depending on the entries in S field.

3. Displaying Results.

The results of the application are displayed on the sheet labeled: "Results". The rate of recruitment, h(i), and the expected number of recruits entering the system, R(i), are displayed as well as their steady state values when they exist. The results shown are either for submodel, A, B, or C. The labeling used in Reference 4: p 64-71 is used to assign the results to the specific submodel. The following is a description of how these results are displayed for each of the three submodels.

a. *Submodel A.*

Results are displayed when all S values and all M values are equal to zero. Submodel A results are labeled h(i) and R(i) for recruitment rates and numbers of recruits, respectively.

b. *Submodel B.*

Results are displayed when S values are not all zero but no new billets are created, i.e. all M values are zero. Submodel B results are labeled h'(i) and R'(i) for recruitment rates and numbers of recruits, respectively.

c. *Submodel C.*

Results are displayed when there is at least one non zero value entered in the M data field. Submodel C results are labeled h''(i) and R''(i) for recruitment rates and numbers of recruits, respectively.

4. Using Results.

The user must copy the results to the " Student Worksheet" in order to use the results for further computations or graphing.

a. *Copy to the "Student Worksheet"*

To copy to the "Student Worksheet", the user must follow these steps:

- Select/highlight the entire area needed to be copied with the mouse.

- Copy, by choosing either of the two steps below.

    - Click the "copy" icon in the toolbar.

    - Using the Edit drop down menu, choose "copy".

- Select the "Worksheet" tab at the bottom of the screen.

- Select the cell where the upper left-hand corner of the data is to be placed by moving the cursor to that cell.

- Choose the "Paste Special" macro at the top of the sheet.

b.   *Graphing.*

If the user needs to graph the results: Copy the values to the "Student Worksheet" and create all graphs on the "Student Worksheet". All other sheets are protected and do not permit graphing.

c.   *Printing.*

All of the Input values and results fit on the first page of their respective sheets for printing purposes. In order to print, the user only needs to press the print icon on the toolbar, when the desired sheet is displayed on the screen.

C.   ERROR TRAPPING/WARNING

1.   Error Displays.

Errors are displayed in bold red letters on the screen. Error messages will only appear when there is an error and they will disappear when the error is corrected. Some mistakes cause two errors to appear. The user should double check the input sheet for any red error messages before looking at the results.

2.   Consequences of Ignoring Warnings.

If the user ignores the warnings, this application will allow the invalid numbers to be input. It will use the flawed inputs and return flawed forecasts. Some warnings come with suggested fixes for the more common errors.

APPENDIX D.   USER'S MANUAL FOR THE MULTIGRADE VACANCY MODEL WITH NON-INSTANTANEOUS FILLING OF VACANCIES

A.   LOADING THE MODEL

In order to use this Excel based model, the user must first open the Excel program that meets the compatibility requirements stated in Appendix A. Once Excel is open, the user should open the file "VACANCY.XLS" located in the subdirectory of the drive in which the model is contained. For users in the Learning Resource Center lab, Glasgow 203, this subdirectory and its location will be provided by the instructor. Users who load the application on their home computer will find the file in the subdirectory to which the user had copied it earlier.

B.   RUNNING THE MODEL

1.   Step (1) Start.

Once the model is displayed on the screen, select the "Start" sheet by clicking on the tab at the bottom of the spreadsheet. A simplified step by step guide to the VACANCY model is presented on this page. A cell for the user's name is also provided on this page. For the inexperienced user, it is recommended that the "Start" sheet be printed and the instructions on it be followed.

2.   Step (2) Choose Model Option.

Choose, by selecting the appropriate tab at the bottom of the spreadsheet, the Vacancy model that best represents the problem. The two options are: Hierarchical (Hier), and General (Gen). For an explanation of the constraints and guidelines for these two options, refer to Chapter IV of this thesis.

3. Step (3) Data Input.

a. *Base Year.*

The base year, e.g. 1998, can be put in by the user or left blank. If left blank, the default base year is "0". The term "year" may mean some period of other than one year duration, such as a month or a quarter.

b. *Forecast.*

This is the number of years the user wants to forecast. This number must be a positive integer no more than 35. Failure to enter a value in this cell will result in a one year forecast. In order to forecast more than 35 periods, follow the directions explained in steps 4 and 5 below.

c. *Alpha.*

This cell requires an entry that represents the rate at which the size of each category in the system changes each period. An entry of .05 indicates that the number of jobs in each category will grow at a rate of 5 percent each period. A negative entry indicates a rate of decline in the number of jobs.

d. *Initial Jobs, Vacancy and Attrition Rate Vectors.*

Both of the above model options require the input of the initial job, initial vacancy and attrition rate vectors. The user is limited to no more than 20 categories.

e. *Transition Rate Matrix.*

Each model option requires specific input to derive the transition rate matrix. The following explanations detail the specific input requirements for each option:

(1) Hierarchical Option. The user must input both the vacancy attrition rates and the vacancy demotion rates in order for the spreadsheet to develop the entire transition rate matrix.

(2) General Option. The user must input all positive elements in the transition rate matrix.

4. Step (4) Reinitializing.

The Reinitialize procedure is used when the user wants to forecast starting with the results obtained from the previous forecast. The user can alter the alpha value and the transition rate matrix. However, the user can not switch from the Hierarchical option to the General option or vice versa.

a. *Prior to Reinitializing.*

The user may want to copy the results from the initial forecast to the worksheet. This procedure is outlined in section 6 of this appendix. It is also advised that the user print out the input page as these numbers will change after reinitializing. To see how to print, go to section 7 of this appendix.

b. *Keeping Track of Periods.*

The easiest method for keeping track of the years is to recognize that the application is always in the base year displayed on the input sheet and is set to forecast into the future.

c. *Pressing the "Reinitialize" Button.*

The user must click the macro button labeled "Reinitialize" located directly to the right of the forecast input cell. The computer then moves the base year ahead by the number of years in the previous forecast, and reinitializes the initial job and initial vacancy values.

d. *Making Changes.*

The user can now alter the alpha value, and change other parameter values within the confines of the problem, to forecast over the next period of years.

e. ***Entering Forecast Value.***

When all changes are made, the user should enter in the forecast cell, the number of periods to forecast.

5. Step (5) Displaying Results.

The results of the application are displayed on three different sheets labeled: "Vacancies", "People", and "Flows". The description of the contents of each sheet follows:

a. ***Vacancies.***

This sheet displays the numbers of vacancies forecast for as many periods as selected by the user.

b. ***People.***

This sheet displays the numbers of personnel filling jobs for as many periods as selected by the user.

c. ***Flows.***

This sheet requires an input value from the user. Because the flow of personnel varies each period in a system, the user must enter the period of concern which must be no greater than the number of periods for which vacancies and personnel were forecast. The sheet then displays the flow of personnel among the various categories during the period selected. For example, the number of people moving from category two to category five is displayed as a value in second row, fifth column, of the output matrix.

6. Step (6) Combining Results of an Initial Forecast and an Additional Forecast.

The user may want to copy the results of each forecast to the "worksheet" in order to create a chronological listing of all results. Failure to do so will erase previous inputs and results. The results can be used for graphing trends, further computations, or simply consolidating the information to one sheet.

a. To Copy to the Worksheet, the User Must Follow these Steps:

- Select/highlight the entire area needed to be copied with the mouse.

- Do not include the initial values in the copying as they are equal to the values in the last year of the initial forecast. For example, if the user did an initial forecast of five years, the initial values of the additional forecast are equal to the results of the initial forecast in year five.

- Copy, by choosing either of the two steps below.

  - Click the "copy" icon in the toolbar.

  - Using the Edit drop down menu, choose "copy".

- Select the "Worksheet" tab at the bottom of the screen.

- Select the cell where the upper left-hand corner of the data is to be placed by moving the cursor to that cell.

- Choose the "Paste Special" macro at the top of the sheet.

b. If the User Needs to Graph the Results:

Copy the values to the "Worksheet" and create all graphs on the "Worksheet". All other sheets are protected and do not permit graphing.

7. Step (7) Printing.

There are several ways to use the "Windows" print functions. One option is to set the print area to encompass only the portion needed. The other option is to print only the first page on any sheet. To set the print area, the user must select with the mouse the cells in question. Then using the function located on the File drop down menu, set the print area. Once set, just press the print icon on the toolbar. To print only one page, the user must select the print command on the File drop down menu and change the commands in the dialog box to "pages 1 to 1" instead of "All". Any other procedure may result in printing some blank pages as well.

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a. *Input.*

The user can choose either printing option if the system contains no more than nine categories when printing the input sheet. If there are more than nine categories, just hit the print icon and the result will be two printed pages.

b. *Results.*

For all of the result pages it is recommended that the user prints page "1 of 1" for all systems with ten categories or less, otherwise blank pages will be printed. If there are more than ten categories, just hit the print icon.

c. *Worksheet.*

Since this is an unprotected sheet, it is the user's responsibility to print only the data needed. The "set print area" method is recommended for this printing.

C. ERROR TRAPPING/WARNING

1. Error Displays.

Errors are displayed in bold red letters on the screen. There may be an error message showing initially. These warnings alert the user that the data field must have a value entered or the procedure of pressing the "Clear entries" macro, must be performed. Otherwise, error messages will only appear when there is an error and they will disappear when the error is corrected. Some mistakes cause two errors to appear. The user should double check the input sheet for any red error messages before looking at the results.

2. Consequences of Ignoring Warnings.

If the user ignores the warnings, this application will allow the invalid numbers to be input. It will use the flawed inputs and return flawed forecasts. Some warnings come with suggested fixes for the more common errors.

APPENDIX E.   USER'S MANUAL FOR THE MULTIGRADE VACANCY MODEL WITH INSTANTANEOUS FILLING OF VACANCIES

A.   LOADING THE MODEL

In order to use this Excel based model, the user must first open the Excel program that meets the compatibility requirements stated in Appendix A. Once Excel is open, the user should open the file "INSTANTANEOUS.XLS" located in the subdirectory of the drive in which the model is contained. For users in the Learning Resource Center lab, Glasgow 203, this subdirectory and its location will be provided by the instructor. Users who load the application on their home computer will find the file in the subdirectory to which the user had copied it earlier.

B.   RUNNING THE MODEL

1.   Explanation of the Model.

This model operates under the assumption that all vacancies are filled instantaneously. While this concept may stretch reality, it may be a good approximation of systems that fill vacancies in time periods that are small fractions of their accounting periods. Since all vacancies are filled instantly, the only results of the model are steady state results. This model is not dependent on time.

2.   Data Input.

There is only one sheet for this model, labeled "Input-Output". All of the input and results are displayed on this one sheet. The user can only enter data in the green cells. The input parameters are further described below.

a.   User's Name.

The purpose of this entry is to identify the user's work on printouts.

b. $\underline{n}$.

This vector of values establishes the number of positions available in each category at the beginning of the period.

c. $\underline{w}$.

$\underline{w}$ is the vector of attrition rates of personnel.

d. $\underline{m}$.

$\underline{m}$ is the vector of the number of jobs being created in each category during a period. A negative value of any component of $\underline{m}$ implies that jobs are being eliminated in that category. If a negative value is entered that eliminates more jobs in the category than the system will allow, a warning will be displayed that tells the user the minimum acceptable value for the offending category. If the user does not make any change, the program will automatically replace that value with a the largest acceptable negative value.

3.   Displaying Results.

The results of this model are contained in a single matrix. The results are displayed on the "Input-Output" sheet.

4.   Using Results.

The user must copy the results to the " Student Worksheet" in order to use the results for further computations or graphing.

a.   Copy to the "Student Worksheet"

To copy to the "Student Worksheet", the user must follow these steps:

- Select/highlight the entire area needed to be copied with the mouse.

- Copy, by choosing either of the two steps below.

  - Click the "copy" icon in the toolbar.

  - Using the Edit drop down menu, choose "copy".

- Select the "Worksheet" tab at the bottom of the screen.

- Select the cell where the upper left-hand corner of the data is to be placed by moving the cursor to that cell.

- Choose the "Paste Special" macro at the top of the sheet.

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b. *Graphing.*

If the user needs to graph the results: Copy the values to the "Student Worksheet" and create all graphs on the "Student Worksheet". The "Input-Output" sheet is protected and does not permit graphing.

c. *Printing.*

All of the Input values and results fit on the first sheet. In order to print, the user only needs to press the print icon on the toolbar. The user will get two printed pages, the first being the input and the second being the output.

C. ERROR TRAPPING/WARNING

1. Error Displays.

Errors are displayed in bold red letters on the screen. Error messages will only appear when there is an error and they will disappear when the error is corrected. Some mistakes cause two errors to appear. The user should double check the input sheet for any red error messages before looking at the results.

2. Consequences of Ignoring Warnings.

If the user ignores the warnings, this application will allow the invalid numbers to be input. It will use the flawed inputs and return flawed forecasts. Some warnings come with suggested fixes for the more common errors.

APPENDIX F.   SAMPLE PROBLEMS USING THE "MARKOV.XLS" MODEL

This appendix includes a set of three examples using the Markov models.   The three examples are taken from Reference 1, pages 101-108.

EXAMPLE 1:

This is Example 4.7 in Reference 1 on pages 107-108.

Input.

This is a Markov length of service system with three categories.   The initial stock vector (100, 60, 480), recruitment proportion vector (1, 0, 0), and attrition rates (.2, .1, .05) are given.   Parts a and b use this initial information to run two separate scenarios.

Part a.

The Recruitment Option is fixed recruitment of 100.   The model is asked to forecast stocks for 30 years under these conditions.

Part b.

The Recruitment Option is fixed system size.   The model is asked to forecast stocks for 5 years under these conditions.

Results.

The input for parts a and b, consolidated output, and steady state stocks are shown on the following pages.

LOS

Matrix Size: 3 X 3

Category	1	2	3	
Enter Initial Stock:	100	60	480	
Recruitment Proportion:	1			
Attrition Rates:	0.2	0.1	0.05	
Continuation Rates:				

NAME: Example 1-a

Attrition

1	0.2		0.8	
2	0.1			0.9
3	0.05			0.95

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6		Enter "1" to Fix Total System Size

Initial recruitment 100

Base Year:
Forecast # of years:(1-35) 30
Number of reinitializations completed

Example 1-a

		Category	1	2	3
		SSSV	100	80	1440
		SSDV	6%	5%	89%

Period	Year	Total (R)	Total (N)	1	2	3
0	0	100	640	100	60	480
1	1	100	690	100	80	510
2	2	100	737	100	80	557
3	3	100	781	100	80	601
4	4	100	823	100	80	643
5	5	100	863	100	80	683
6	6	100	900	100	80	720
7	7	100	936	100	80	756
8	8	100	971	100	80	791
9	9	100	1003	100	80	823
10	10	100	1034	100	80	854
11	11	100	1063	100	80	883
12	12	100	1091	100	80	911
13	13	100	1117	100	80	937
14	14	100	1143	100	80	963
15	15	100	1166	100	80	986
16	16	100	1189	100	80	1009
17	17	100	1211	100	80	1031
18	18	100	1231	100	80	1051
19	19	100	1251	100	80	1071
20	20	100	1269	100	80	1089
21	21	100	1287	100	80	1107
22	22	100	1303	100	80	1123
23	23	100	1319	100	80	1139
24	24	100	1334	100	80	1154
25	25	100	1348	100	80	1168
26	26	100	1362	100	80	1182
27	27	100	1375	100	80	1195
28	28	100	1387	100	80	1207
29	29	100	1399	100	80	1219
30	30	100	1410	100	80	1230

Matrix Size: 3 X 3

Category	1	2	3	
Enter Initial Stock:	100	60	480	
Recruitment Proportion:	1			
Attrition Rates:	0.2	0.1	0.05	
Continuation Rates:				

NAME: Example 1-b

Attrition

	1	2	3	4	5
1	0.2		0.8		
2	0.1			0.9	
3	0.05			0.95	

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6	1	Enter "1" to Fix Total System Size

Initial recruitment

Base Year:

Forecast # of years:(1-35) 5

Number of reinitializations completed

Example 1-b

				Category 1	2	3
				SSSV 40	32	569
				SSDV 6%	5%	89%

Period	Year		Total (R)	Total (N)	1	2	3
0	0		50	640	100	60	480
1	1		44	640	50	80	510
2	2		41	640	44	40	557
3	3		40	640	41	35	565
4	4		40	640	40	32	568
5	5		40	640	40	32	569

EXAMPLE 2:

This is Example 4.3 in Reference 1 on pages 101-102.

Input.

This is a Markov Hierarchical system with four categories. The initial stock vector (600, 400, 330, 70) and recruitment proportion vector (1, 0, 0, 0) are given as well as the promotion (.61, .71, .2) and attrition rates (.24, .18, .7, .95) The initial Recruitment Option is fixed recruitment of 500.

The model is asked to forecast stocks for three years under the initial conditions. Then recruitment is changed to 700 and the model is asked to forecast years four and five. Then recruitment is reset to the initial value of 500 and forecasting is resumed for years six through 20.

Results.

The initial and two subsequent inputs, the consolidated output, and steady state stocks are shown on the following pages.

Matrix Size: 4   X   4

Category	1	2	3	4
Enter Initial Stock:	600	400	330	70
Recruitment Proportion:	1			
Attrition Rates:	0.24	0.18	0.7	0.95
Promotion Rates:	0.61	0.71	0.2	

Enter   4

Enter   3

NAME: Example 2

Category

	1	2	3	4	
1	0.15	0.61			
2		0.11	0.71		
3			0.1	0.2	
4				0.05	

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6		Enter "1" to Fix Total System Size

Initial recruitment 500

Base Year:

Forecast # of years:(1-35) 3

Number of reinitializations completed

Matrix Size: 4 X 4

Category	1	2	3	4	
Enter Initial Stock:	585	404	320	68	
Recruitment Proportion:	1				
Attrition Rates:	0.24	0.18	0.7	0.95	
Promotion Rates:	0.61	0.71	0.2		

Enter 4

Enter 3

NAME: Example 2

Category	1	2	3	4	
1	0.15	0.61	.		
2		0.11	0.71		
3			0.1	0.2	
4				0.05	

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6		Enter "1" to Fix Total System Size

Initial recruitment 700

Base Year: 3

Forecast # of years:(1-35) 2

Number of reinitializations completed 1

Matrix Size: 4 X 4

Category	1	2	3	4	
Enter Initial Stock:	615	525	315	67	
Recruitment Proportion:	1				
Attrition Rates:	0.24	0.18	0.7	0.95	
Promotion Rates:	0.61	0.71	0.2		

Enter 4
Enter 3

NAME: Example 2

Category					
1	0.15	0.61			
2		0.11	0.71		
3			0.1	0.2	
4				0.05	

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6		Enter "1" to Fix Total System Size

Initial recruitment 500

Base Year:	5
Forecast # of years:(1-35)	15
Number of reinitializations completed	2

Example 2

	Category	1	2	3	4
	SSSV	588	403	318	67
	SSDV	43%	29%	23%	5%

Period	Year	Total (R)	Total (N)	1	2	3	4
0	0	500	1400	600	400	330	70
1	1	500	1387	590	410	317	70
2	2	500	1383	589	405	323	67
3	3	500	1380	588	404	320	68
1	4	700	1577	788	403	318	67
2	5	700	1729	818	525	318	67
1	6	500	1651	623	557	405	67
2	7	500	1555	593	441	436	84
3	8	500	1448	589	411	357	91
4	9	500	1396	588	404	327	76
5	10	500	1381	588	403	320	69
6	11	500	1377	588	403	318	67
7	12	500	1377	588	403	318	67
8	13	500	1376	588	403	318	67
9	14	500	1376	588	403	318	67
10	15	500	1376	588	403	318	67
11	16	500	1376	588	403	318	67
12	17	500	1376	588	403	318	67
13	18	500	1376	588	403	318	67
14	19	500	1376	588	403	318	67
15	20	500	1376	588	403	318	67

EXAMPLE 3:

This is Example 4.6 in Reference 1 on pages 105-106.

Input.

This is a Markov General system with four categories. The initial stock vector (129, 74, 28, 11), recruitment proportion vector (1, 0, 0, 0), and transition rate matrix (see following page) are given. Fixed total system size is the initial Recruitment Option.

The model forecasts for five years under the initial assumptions. For years six through 15, system size is set to increase by 24 each year. For years 16 through 30, the model returns to fixed system size at the size in year 15.

Results.

The initial and subsequent inputs, consolidated output, and steady state stocks are shown on the following pages.

Matrix Size: 4   X   4

	1	2	3	4	
Enter Initial Stock:	129	74	28	11	
Recruitment Proportion:	1				

NAME: [Example 3]

	Category	Attrition	1	2	3	4	
Enter 1st Row of P-Matrix	1	0.170	0.728	0.102			
Enter 2nd Row of P-Matrix	2	0.124		0.83	0.046		
Enter 3rd Row of P-Matrix	3	0.100			0.867	0.033	
Enter 4th Row of P-Matrix	4	0.098				0.902	
NO MORE ENTRIES							

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6	1	Enter "1" to Fix Total System Size

Initial recruitment

Base Year:

Forecast # of years:(1-35)   5

Number of reinitializations completed

Matrix Size: 4 X 4

	1	2	3	4
Enter Initial Stock:	129	76	27	10	
Recruitment Proportion:	1				

NAME: Example 3

	Category	Attrition	1	2	3	4	
Enter 1st Row of P-Matrix	1	0.170	0.728	0.102			
Enter 2nd Row of P-Matrix	2	0.124		0.83	0.046		
Enter 3rd Row of P-Matrix	3	0.100			0.867	0.033	
Enter 4th Row of P-Matrix	4	0.098				0.902	
NO MORE ENTRIES							

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4	24	Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6		Enter "1" to Fix Total System Size

Initial recruitment

Base Year:	5
Forecast # of years:(1-35)	10
Number of reinitializations completed	1

Matrix Size: 4 X 4

	1	2	3	4	
Enter Initial Stock:	304	134	33	10	
Recruitment Proportion:	1				

NAME: [Example 3]   ·· Category Attrition

	Category	Attrition	1	2	3	4	
Enter 1st Row of P-Matrix	1	0.170	0.728	0.102			
Enter 2nd Row of P-Matrix	2	0.124		0.83	0.046		
Enter 3rd Row of P-Matrix	3	0.100			0.867	0.033	
Enter 4th Row of P-Matrix	4	0.098				0.902	
NO MORE ENTRIES							

Recruitment Option:	1	default	Fixed Recruitment
Recruitment Option:	2		Additive Increase or Decrease:
Recruitment Option:	3		Multiplicative Increase or Decrease:[-1,1]
Recruitment Option:	4		Additive Increase or Decrease in Total System Size:
Recruitment Option:	5		Mult inc/dec in Total System Size [-1,1] Except 0
Recruitment Option:	6	1	Enter "1" to Fix Total System Size

Initial recruitment

Base Year: 15
Forecast # of years:(1-35) 15
Number of reinitializations completed 2

Example 3

Category	1	2	3	4
SSSV	257	154	53	18
SSDV	53%	32%	11%	4%

Period	Year	Total (R)	Total (N)	1	2	3	4
0	0	35	242	129	74	28	11
1	1	35	242	129	75	28	11
2	2	35	242	129	75	27	11
3	3	35	242	129	75	27	11
4	4	35	242	129	76	27	10
5	5	35	242	129	76	27	10
1	6	63	266	153	76	27	10
2	7	67	290	174	79	27	10
3	8	71	314	194	83	27	10
4	9	75	338	212	89	27	10
5	10	79	362	229	95	28	10
6	11	82	386	245	103	28	10
7	12	86	410	261	110	29	10
8	13	90	434	276	118	30	10
9	14	93	458	290	126	32	10
10	15	97	482	304	134	33	10
1	16	72	482	294	142	35	10
2	17	72	482	287	148	37	10
3	18	71	482	280	152	39	10
4	19	71	482	276	155	41	11
5	20	71	482	272	157	42	11
6	21	71	482	269	158	44	11
7	22	71	482	266	158	45	12
8	23	71	482	265	159	47	12
9	24	70	482	263	159	48	12
10	25	70	482	262	159	49	13
11	26	70	482	261	158	50	13
12	27	70	482	260	158	50	13
13	28	70	482	260	158	51	14
14	29	70	482	259	157	51	14
15	30	70	482	259	157	52	14

APPENDIX G. SAMPLE PROBLEMS USING THE "REPLACE.XLS" MODEL

This appendix includes a set of three examples using the One Grade Vacancy model. The three examples are taken from Reference 1, pages 141-144.

EXAMPLE 1:

This is Example 5.1 in Reference 1 on pages 141-142.

Input.

This is a case of a Submodel A system. All employees start with no initial length of service distribution and no jobs are created in later periods.

The fixed system size (100) and the survivor rates (1, .6, .45, .38, .34, .32, .3, .29) are given. The model computes the replacement rates, $h(i)$, and the number of recruits, $R(i)$, for the next 31 periods.

Results.

The input, output, and steady state values are shown on the following pages. Note: the results do not agree with those in Reference 1, because here the survival rates are assumed to diminish gradually at a uniform rate of 1.2 percent per period beyond the last input value of $G(7) = .290$. This is a more realistic assumption than the one made by Reference 1, which is that $G(8) = 0$.

Enter Name: Example-1

N	100

Time (i)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
f																
G	1	0.600	0.450	0.380	0.340	0.320	0.300	0.290								

Initial Employee LOS:

S																

Number of Jobs Created
t Time (i)

M	0

Use this area to enter data
For time (i) greater than 15

f	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
G																
S																
M																

The f values from f 7
through f 31 are
distributed evenly.
(0-15)
(16-31)

F	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0.400	0.150	0.070	0.040	0.020	0.020	0.010	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.000

The G values from G 7
through G 31 are
decreasing evenly.
(0-15)
(16-31)

G	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1.000	0.600	0.450	0.380	0.340	0.320	0.300	0.290	0.278	0.266	0.254	0.242	0.230	0.218	0.205	0.193
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	0.181	0.169	0.157	0.145	0.133	0.121	0.109	0.097	0.085	0.073	0.060	0.048	0.036	0.024	0.012	0.000

Name: <u>Example-1</u>

Results

h	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	40	31	25	22	18	16	14	13	12	12	11	11	11	11	11

| | 1.0000 | 0.4000 | 0.3100 | 0.2540 | 0.2161 | 0.1822 | 0.1635 | 0.1422 | 0.1302 | 0.1216 | 0.1158 | 0.1122 | 0.1102 | 0.1095 | 0.1098 | 0.1108 |

h	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	0.1125	0.1146	0.1170	0.1198	0.1229	0.1262	0.1296	0.1333	0.1371	0.1411	0.1452	0.1495	0.1539	0.1585	0.1632	0.1680
R	11	11	12	12	12	13	13	13	14	14	15	15	15	16	16	17

Steady State

h	0.1426
R	14

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EXAMPLE 2:

This is Example 5.2 in Reference 1 on page 142.

Input.

This is a case of a Submodel B system. This example has the same input parameters as Example 1 with the additional information that the initial population has a given length of service distribution. No jobs are created in the later periods.

The fixed system size (100), the survivor rates (1, .6, .45, .38, .34, .32, .3, .29), and the distribution of the population length of service distribution (.5, .3, .1, .1) are given. The model computes the replacement rates, h'(i), and the number of recruits, R'(i).

Results.

The input, output, and steady state values are shown on the following pages. Note: results do not agree with those given in Reference 1 for reasons explained in Example 1.

Input

Enter Name: Example-2

Time (i)

N	100	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
f																		

Number of Jobs Created
t Time (i)

M	0																

Initial Employee LOS:

S	0.5	0.3	0.1	0.1													

G	1	0.600	0.450	0.380	0.340	0.320	0.300	0.290									

Use this area to enter data
For time (i) greater than 15

f	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
G																
S																
M																

The f values from f 7
through f 31 are
distributed evenly.

(0-15)
(16-31)

F	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0.400	0.150	0.070	0.040	0.020	0.020	0.010	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.000

The G values from G 7
through G 31 are
decreasing evenly.

(0-15)
(16-31)

G	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1.000	0.600	0.450	0.380	0.340	0.320	0.300	0.290	0.278	0.266	0.254	0.242	0.230	0.218	0.205	0.193
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	0.181	0.169	0.157	0.145	0.133	0.121	0.109	0.097	0.085	0.073	0.060	0.048	0.036	0.024	0.012	0.000

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Name: __Example-2__

h'	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
h'	1.0000	0.3011	0.2446	0.2077	0.1779	0.1569	0.1407	0.1284	0.1206	0.1153	0.1121	0.1105	0.1101	0.1106	0.1118	0.1135
R'	0	30	24	21	18	16	14	13	12	12	11	11	11	11	11	11

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
h'	0.1157	0.1183	0.1212	0.1243	0.1276	0.1312	0.1349	0.1388	0.1428	0.1470	0.1513	0.1558	0.1604	0.1620	0.1630	0.1599
R'	12	12	12	12	13	13	13	14	14	15	15	16	16	16	16	16

Steady State

h'	0.1426
R'	14

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EXAMPLE 3:

This is Example 5.3 in Reference 1 on pages 143-144.

Input.

This is a case of a Submodel C system. This example has the same input parameters as Example 2 with additional information provided on new jobs created in subsequent years.

The fixed system size (100), the survivor rates (1, .6. .45, .38, .34, .32, .3, .29), the distribution of the population length of service distribution (.5, .3, .1, .1), and the number of new jobs created in later years (10, 15, 20, 25) are given. The model computes the replacement rates, h''(i), and the number of recruits, R''(i).

Results.

The input and output values are shown on the following pages. Note: results do not agree with those given in Reference 1 for reasons explained in Example 1.

Enter Name: **Example-3**

Time (i)

N	100

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
f																
G	1	0.600	0.450	0.380	0.340	0.320	0.300	0.290								

Initial Employee LOS:

S	0.5	0.3	0.1	0.1

Number of Jobs Created t Time (i)

M	0	10	15	20	25

Use this area to enter data
For time (i) greater than 15

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
f																
G																
S																
M																

The f values from f 7 through f 31 are distributed evenly.

The G values from G 7 through G 31 are decreasing evenly.

F

(0-15)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.400	0.150	0.070	0.040	0.020	0.020	0.010	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012

(16-31)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.000

G

(0-15)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.000	0.600	0.450	0.380	0.340	0.320	0.300	0.290	0.278	0.266	0.254	0.242	0.230	0.218	0.205	0.193

(16-31)

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.181	0.169	0.157	0.145	0.133	0.121	0.109	0.097	0.085	0.073	0.060	0.048	0.036	0.024	0.012	0.000

Name: **Example-3**

Results

h "	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
h "	1.0000	0.4011	0.3951	0.3990	0.3999	0.2227	0.1880	0.1640	0.1469	0.1341	0.1254	0.1188	0.1150	0.1129	0.1121	0.1124
R "	0	40	43	50	58	38	32	28	25	23	21	20	20	19	19	19

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
h "	0.1134	0.1150	0.1171	0.1196	0.1225	0.1256	0.1289	0.1325	0.1362	0.1401	0.1441	0.1484	0.1527	0.1554	0.1577	0.1577
R "	19	20	20	21	21	22	23	23	24	25	25	26	26	26	27	27

Steady State

h "	DNE
R "	DNE

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APPENDIX H.   SAMPLE PROBLEMS USING THE "VACANCY.XLS" MODEL

This appendix includes a set of three examples using the vacancy model with non instantaneous filling of vacancies. The three examples are taken from Reference 1, pages 153-156.

EXAMPLE 1:

This is a modification of Example 5.6 in Reference 1 on page 153.

Input.

This is a case of a Hierarchical vacancy system with three categories. The General input option is used for the purpose of illustration. The initial job vector (300, 200, 100), initial vacancy vector (0, 0, 0), attrition rate vector (.2, .05, .1), and the $\underline{S}$ matrix (see following page) are given.

The model computes stocks for five years under these conditions.

After the first five years, alpha is reset to increase ten percent per year, for five years.

Results.

The input and output sheets are shown on the following pages.

Name: Example-1
Matrix Size
3 X 3

Base Year		
Forecast	5	
Alpha	0.00	Default = 0

Number of reinitializations completed
Blank = None

Category	1	2	3
Initial Jobs	300	200	100
Initial Vacancies	0	0	0
Attrition Rates	0.200	0.050	0.100

Enter 3

Category Vac Attrition

	Category			
Enter S flow rates	1	1		
Enter S flow rates	2	0	1.000	
Enter S flow rates	3	0		1.000

NO MORE ENTRIES

Name: <u>Example-1</u>
Matrix Size
3 X 3

	Base Year	5		
	Forecast	5		
	Alpha	0.10	Default = 0	
	Category	1	2	3

1 Number of reinitializations completed
Blank = None

		1	2	3								
	Initial Jobs	300	200	100								
Enter 3	Initial Vacancies	65	18	9								
	Attrition Rates	0.200	0.050	0.100								

Category Vac Attrition

		1											
Enter S flow rates	1	**1**											
Enter S flow rates	2	0	1.000										
Enter S flow rates	3	0		1.000									
NO MORE ENTRIES													

Name: **Example-1**

B. Year	Period	Total	Vacancies Category	1	2	3
0	0	0		0	0	0
1	1	80		60	10	10
2	2	87		58	20	9
3	3	95		68	18	9
4	4	92		64	18	9
5	5	93		65	18	9
6	1	152		95	38	19
7	2	188		118	50	20
8	3	212		135	54	22
9	4	230		147	59	24
10	5	254		162	65	27

B. Year	Period	Total	People Category	1	2	3
0	0	600		300	200	100
1	1	520		240	190	90
2	2	514		242	181	91
3	3	505		232	182	91
4	4	508		236	182	91
5	5	507		235	182	91
6	1	508		235	182	91
7	2	538		245	192	101
8	3	587		264	212	111
9	4	648		293	233	122
10	5	712		321	257	134

Flows during
Base Year ⟶ 5

$P_{ij}(t)$	1	2	3
Recruits	64	0	0
1	0	18	0
2	0	0	9
3	0	0	0

Flows during
Base Year ⟶ 10

$P_{ij}(t)$	1	2	3
Recruits	147	0	0
1	0	59	0
2	0	0	24
3	0	0	0

EXAMPLE 2:

This is a modification of Example 5.9 in Reference 1 on pages 155-156.

Input.

This is a case of a Hierarchical vacancy system with three categories. The General input option is used for the purpose of illustration. The initial job vector (300, 200, 100), initial vacancy vector (0, 0, 0), attrition rate vector (.2, .05, .1), and the $\underline{S}$ matrix (see following page) are given.

The model is asked to forecast stocks for five years under these conditions.

After the first five years, alpha is reset to decrease five percent per year, for five years.

Results.

The input and output sheets are shown on the following pages.

Name: Example-2
Matrix Size
3 X 3

Base Year [ ]
Forecast [5]
Alpha [0.00] Default = 0

[ ] **Number of reinitializations completed**
Blank = None

Category	1	2	3							
Initial Jobs	300	200	100							
Initial Vacancies	0	0	0							
Attrition Rates	0.200	0.050	0.100							

Enter   3

Category Vac Attrition

	Category	Vac	Attrition									
Enter S flow rates	1	0.7	0.300									
Enter S flow rates	2	0	0.800	0.200								
Enter S flow rates	3	0		0.900	0.100							
NO MORE ENTRIES												

Name: Example-2
Matrix Size
3 X 3

		Base Year	5										
		Forecast	5					1	Number of reinitializations completed				
		Alpha	-0.05	Default = 0					Blank = None				
		Category	1	2	3								
		Initial Jobs	300	200	100								
Enter	3	Initial Vacancies	86	22	10								
		Attrition Rates	0.200	0.050	0.100								

Category Vac Attrition

Enter S flow rates	1	0.7	0.300										
Enter S flow rates	2	0	0.800	0.200									
Enter S flow rates	3	0		0.900	0.100								
NO MORE ENTRIES													

Name: **Example-2**

B. Year	Period	Total	Vacancies Category	1	2	3
0	0	0		0	0	0
1	1	80		60	10	10
2	2	105		74	21	10
3	3	116		84	22	10
4	4	118		86	22	10
5	5	119		86	22	10
6	1	89		72	12	5
7	2	71		60	6	5
8	3	61		52	5	5
9	4	57		48	5	4
10	5	54		45	5	4

B. Year	Period	Total	People Category	1	2	3
0	0	600		300	200	100
1	1	520		240	190	90
2	2	496		226	180	90
3	3	484		216	178	90
4	4	482		214	178	90
5	5	481		214	178	90
6	1	481		213	178	90
7	2	471		211	174	86
8	3	453		206	166	81
9	4	432		196	158	77
10	5	410		187	150	73

Flows during
Base Year ⟶ 5

$P_{ij}(t)$	1	2	3
Recruits	60	0	0
1	26	18	0
2	0	4	9
3	0	0	1

Flows during
Base Year ⟶ 10

$P_{ij}(t)$	1	2	3
Recruits	34	0	0
1	14	4	0
2	0	1	4
3	0	0	0

EXAMPLE 3:

This is Example 5.10 in Reference 1 on page 156.

Input.

This is a case of a Hierarchical vacancy system with three categories. The initial job vector (300, 200,100), initial vacancy vector (0, 0, 0), attrition rate vector (.2, .05, .1), vacancy attrition vector (1.0, .4, .2), vacancy demotion rates (.6, .8), and alpha (0.00) are given.

The model is asked to forecast stocks for five years under these conditions.

Results.

The input and output sheets are shown on the following pages.

Name: Example-3
Matrix Size
3 X 3

	Base Year				Number of reinitializations completed
	Forecast	5			
	Alpha	0.00	Default = 0		Blank = None

	Category	1	2	3
	Initial Jobs	300	200	100
Enter 3	Initial Vac	0	0	0
	Attrition Rates	0.200	0.050	0.100
	Vac Attrition	1.000	0.400	0.200
	Vac Demotions	0.600	0.800	

Category Vac Attrition

Enter S flow rates	1	**1.000**	0		
Enter S flow rates	2	**0.400**	0.6	0	
Enter S flow rates	3	**0.200**		0.8	0
NO MORE ENTRIES					

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Student Worksheet

Name: **Example-3**

B. Year	Period	Total	Vacancies Category	1	2	3
0	0	0		0	0	0
1	1	80		60	10	10
2	2	81		54	18	9
3	3	85		60	16	9
4	4	83		58	16	9
5	5	84		58	16	9

B. Year	Period	Total	People Category	1	2	3
0	0	600		300	200	100
1	1	520		240	190	90
2	2	520		246	183	91
3	3	515		240	184	91
4	4	517		242	184	91
5	5	516		242	184	91

Flows during
Base Year   ⟶   5

$P_{ij}(t)$	1	2	3
Recruits	58	7	2
1	0	10	0
2	0	0	7
3	0	0	0

APPENDIX I. SAMPLE PROBLEMS USING THE "INSTANTANEOUS.XLS" MODEL

This appendix includes a set of three examples using the Vacancy model with instantaneous filling of vacancies. The three examples are taken from Reference 1, pages 147-151.

EXAMPLE 1:

This is Example 5.4 in Reference 1 on pages 147-148.

Input.

This is a case of a Hierarchical vacancy system with three categories. The initial job vector (140, 105, 35), attrition rate vector (.2, .1, .15), and $\underline{S}$ matrix (see following page) are given.

Results.

The input and output sheet is shown on the following page.

Name   **Example-1**

	1	2	3						
n	140	105	35						
w	0.200	0.100	0.150						
m									

Vac attrition	1	2	3						
Enter 1st row of S matrix	1.00								
nter 2nd row of S matrix	0.40	0.6							
nter 3rd row of S matrix	0.40		0.6						

Attrition   Category

		1	2	3						
	Recruits	36	5	2						
28	1	0	8	0						
11	2	0	0	3						
5	3	0	0	0						

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EXAMPLE 2:

This is Example 5.5 in Reference 1 on pages 150-151.

Input.

This is a case of a General vacancy system with five categories. The initial job vector (2500, 1500, 1000, 500, 150), attrition rate vector (.2, .15, .1, .1, .05), and the $\underline{S}$ matrix (see following page) are given.

Results.

The input and output sheet is shown on the following page.

Name | Example-2

	1	2	3	4	5				
n	2500	1500	1000	500	150				
w	0.200	0.150	0.100	0.100	0.050				
m									

Vac attrition		1	2	3	4	5				
Enter 1st row of S matrix	0.95	0.0494	0.0031	0.0004						
nter 2nd row of S matrix	0.10	0.6125	0.2811	0.0024						
nter 3rd row of S matrix	0.10	0.0015	0.5539	0.3443						
nter 4th row of S matrix	0.13		0.0169	0.7022	0.1404	0.0056				
nter 5th row of S matrix	0.13				0.6635	0.2115				

Attrition

		Category								
		1	2	3	4	5				
	Recruits	799	51	23	9	1				
500	1	42	301	0	0	0				
225	2	3	138	125	1	0				
100	3	0	1	78	46	0				
50	4	0	0	0	9	7				
8	5	0	0	0	0	2				

EXAMPLE 3:

This is a modification of Example 5.5 in Reference 1 on pages 150-151.

Input.

This is a case of a General vacancy system with five categories. This problem has the same input values as Example 2 of this appendix, and additional information on the changing job structure. The initial job vector (2500, 1500, 1000, 500, 150), attrition rate vector (.2, .15, .1, .1, .05), $\underline{m}$ vector (-100, 60, -50, 25, -5), and $\underline{S}$ matrix (see following page) are given.

Results.

The input and output sheet is shown on the following page.

Name | Example-3

	1	2	3	4	5				
n	2500	1500	1000	500	150				
w	0.200	0.150	0.100	0.100	0.050				
m	-100	60	-50	25	-5				

Vac attrition		1	2	3	4	5				
Enter 1st row of S matrix	0.95	0.0494	0.0031	0.0004						
nter 2nd row of S matrix	0.10	0.6125	0.2811	0.0024						
nter 3rd row of S matrix	0.10	0.0015	0.5539	0.3443						
nter 4th row of S matrix	0.13		0.0169	0.7022	0.1404	0.0056				
nter 5th row of S matrix	0.13				0.6635	0.2115				

Attrition | **Category**

Attrition			1	2	3	4	5				
		Recruits	726	56	18	12	0				
500	1		38	329	0	0	0				
225	2		2	151	97	2	0				
100	3		0	1	60	63	0				
50	4		0	0	0	13	3				
8	5		0	0	0	1	1				

LIST OF REFERENCES

1. Bartholomew, D.J., Forbes, A.F., and McClean, S.I., *Statistical Techniques for Manpower Planning -2nd ed.*, John Wiley & Sons Ltd,. 1991.

2. *Naval Postgraduate School Catalog, Academic Year 1998*, Naval Postgraduate School, Monterey, CA.

3. Gurdal, A.E., *Basic Computer Models for Manpower Planning*, Master's Thesis, Naval Postgraduate School, Monterey, CA, March 1991.

4. Milch, P.R., *Manpower and Personnel Models*, Class notes for OS4701, Naval Postgraduate School, Monterey, CA, November 1997.

5. Depuy, N.B., *Steady State Distributions for Manpower Models Under Conditions of Growth*, Master's Thesis, Naval Postgraduate School, Monterey, CA, September 1985.

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